RADIOSCIENCE LABORATORY

STANFORD UNIVERSITY

Stanford, California

9 July, 1967 10.

RESEARCH AT THE STANFORD CENTER FOR RADAR ASTRONOMY

Semi-Annual Status Report No. 9

for the period 1 January - 30 June, 1967

Research Grant No. NsG-377

SEL Project No. 3208

FACILITY FORM 602		
N67-84785 (ACCESSION NUMBER)		(THRU)
14 (PAGES)		None (CODE)
CR-85547 (NASA CR OR TMX OR AD NUMBER)		(CATEGORY)

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Prepared for the:

NATIONAL AERONAUTICS AND SPACE ADMINISTRATION
Washington, D. C. 20546

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INTRODUCTION

The Stanford Center for Radar Astronomy (SCRA) is a joint venture of Stanford University (SU) and the Stanford Research Institute (SRI) to facilitate cooperative efforts (scientific, engineering and graduate student training) in radar astronomy and space science. The common interest in this field has grown out of basic and applied research programs at both groups for radar studies of the upper atmosphere and interplanetary space.

NASA grant NsG-377 funds have been used for a number of theoretical and experimental investigations in radio and radar studies of space plasmas (the interplanetary medium, the earth's magnetospheric wake, the solar corona, planetary ionosphere, etc.), lunar and planetary surfaces, communication theory, and spacecraft instrumentation.

An important result obtained during the reporting period has come from processing the direct and moon-reflected S-band signals transmitted by Lunar Orbiter III. These signals, when properly analyzed, should produce a two-dimensional surface image. To date, preliminary analysis has located several radio frequency bright spots which correspond with visual features and which also stand out in earth-based, monostatic, range-doppler, radar maps. Since the planetary application of bistatic radar mapping is very promising, two different processing techniques are being pursued simultaneously--one optical and the other digital. A paper is now in press [Tyler, G. L., et al, Bistatic-radar detection of scattering centers on the moon using Lunar Orbiter I, Science, in press] describing initial results, and a dissertation has been completed on the broad subject of bistatic radar for planetary surface studies. The present status of this work is described in this report under the heading "Planetary Surface Mapping."

The final results of the FM-CW lunar radar program have now been published [H. T. Howard, J. Geophys. Res., 72, June, 1967]. It is important to note that after the publication of Scientific Report No. 17 [NsG-377, SU-SEL-66-113], newly analyzed data from Explorer 22 for the experiment period became available. Comparison of these results with the Radar and Syncom measurements made it clear that the large electron concentrations previously attributed to the earth's "tail" were, in fact, located between 1000 km and the plasmapause. Thus, it is concluded that, within the $\pm$ 30 electrons cm^{-3} accuracy of the combined measurement, the electron number density in the geomagnetic tail is not markedly different from that of interplanetary space.

In the following section, brief reports are given of the activities of graduate students and research associates during the period.

Monostatic Radar Astronomy

During the last reporting period, a considerable amount of the 6- and 12-meter lunar chirp radar data was reduced digitally to display echo power as a function of range. Before this could be done, it was necessary to determine exactly what relation the signals recorded on tape had to the desired power-versus-range information and to find a suitable section from the many days of data to analyze. A program for the IBM 7090 was written to do the necessary spectral analysis on the proper sections of the previously digitized data. This program uses the Cooley-Tukey method to take the Fourier transform rapidly and manipulates the data so that the spectra are over-sampled (i.e., having half the frequency separation between estimates than is theoretically necessary) and so that both the 6- and 12-meter data are analyzed simultaneously. About 40 minutes of data (about 500 echoes) have been analyzed so far.

The interpretation of these echoes is the next step. The range resolution of the system is slightly larger than 10 μsec which is considerably better than previously obtained at these wavelengths, so the scattering properties of the moon can be examined in greater detail, particularly since the leading-edge spike can be resolved.

An individual echo appears to consist of a number of high peaks superimposed on a ragged but less variable background, particularly at 12 meters. Occasionally, the "leading-edge peak" is not even the highest, but in general both the amplitude and the number of peaks decrease with increasing range. Since many peaks persist for 15 seconds or more, it is felt that specular reflections account for most of the scattering.

To test this hypothesis, several things will be tried. These include correlating the echoes at 6 and 12 meters since a specular reflecting point should be simultaneously specular to both frequencies, and attempting to measure the polarization of the echoes (on the average) using the natural Faraday rotation. During a Faraday fade, the depolarized component of the echo is received and specular reflection doesn't depolarize the signal whereas the diffuse component tends to. It is also hoped to obtain a distribution function for the specular component by merely counting specular points.

Planetary Surface Mapping

Efforts have been directed toward the development of bistatic radar techniques for the imaging and the study of planetary surfaces. During the current reporting period, this has involved activities in four areas: the collection of flight data from Lunar Orbiter III continued with an optical processor for data reduction, the implementation of fast computer algorithms for digital data reduction, and the completion of a theoretical analysis of the technique.

1. Lunar Orbiter III

Lunar Orbiter III was used as a transmitting source to obtain signals from the surface of the moon. The spacecraft high-gain antenna was used to direct the transmissions toward localized regions of the lunar surface. In all, it was possible to scan three distinct areas of the disk. The first of these was the crater Langrenus, which is a comparatively new feature known to be a good radar scatter from ground-based radar observations. Extremely strong signals were obtained in this observation, and time-frequency spectral analysis reveals considerable radar structure of the crater and of the surrounding area. The second observation covered a strip which starts just above the crater Colombo, continues across Mare Fecunditates, and passes below Langrenus. The observation has several very distinct time frequency traces near the origin of the record which have been tentatively associated with full-moon bright objects on the western shore of Fecunditatis. The third observation scanned the area of Apollo sites I and II. The analysis so far has not revealed any distinct radar features in this area.

2. Optical Processing Techniques

Work in this area has consisted of refining the techniques developed in the preceding report period. The following has been accomplished.

a) The reconstruction noise power associated with the optical system itself has been reduced approximately 23 db.

b) Primary observations have been eliminated.

c) Simple procedures have been developed for aligning the record in the illuminating slit.

d) Computer techniques have been developed for pre-processing the data in preparation for optical reconstruction.

e) The quantitative relationship between the simulated data and the actual data have been obtained.

In spite of these advances in the quality of the processing system, a recognizable reconstruction has continued to elude us. However, there are still some refinements involving additional pre-processing of the data, which have yet to be realized.

3. Digital Processing Techniques

The fast algorithms mentioned in the preceding report have been implemented and are in use by several members of the Stanford Center for Radar Astronomy. Studies are now under way to determine the most efficient overall methods for various types of spectral analysis while conforming to the peculiarities of the algorithms. Eventually, these techniques will be applied to the radar imaging problem.

4. Theoretical Studies

A thesis (Ph.D.) entitled "Bistatic-Radar Imaging and Measurement Techniques for the Study of Planetary Surfaces" has been completed. Much of this work was completed and compiled during this report period.

Solar Radar Program

Reduction of data taken with the Stanford solar radar system during the summers of 1963, 1964 and 1965 has been completed. The results indicate that the average cross-section of the sun during each of these three investigation periods was less than one photospheric area. This was concluded since no positive indication of returned signals were evident in any of the data, even when all of the over 200 runs were summed together, and that the system sensitivity is such that a signal (via summation of many runs) corresponding to one photospheric cross-section would be detectable.

The validity of the system has been demonstrated by considering each segment of the overall system and verifying its proper operation. Briefly, the following described the checks of the major components in the system.

The proper direction of the antenna has been verified by five years of lunar radar experiments using the same transmitter and antenna. The calculation of antenna parameters is identical for lunar and solar work.

The analog-to-digital conversion and the resultant cross-correlation was verified with test signals of various types. Finally, use was made of solar radar data taken at the El Campo Station of the MIT Center for Space Research. Their data was in a nearly identical format to our own and it was reduced on our systems. Echo indications were obtained with the same magnitude as MIT observed.

In conclusion, the radar cross-section appears to be at least as small or smaller at 25 MHz (the Stanford Frequency) than at 30 MHz (MIT frequency) during the years of low solar activity. This is not in agreement with the present theory which predicts the opposite case. Since the MIT group is still obtaining relatively weak echoes, no attempts are being made at present to obtain echoes at Stanford.

A thesis (Ph.D.) entitled "A Radar Investigation of the Solar Corona" has been completed during the reporting period.

Spacecraft Instruments and Techniques

Since the original development of the Stanford Pioneer and Mariner Instruments a number of years ago, the state of the transistor art has advanced considerably. One of the basic limitations to the ultimate range capability has been receiver noise in the 423.3 MHz channel. Now a small (less than 50 grams) preamplifier has been designed and constructed. At Stanford Research Institute, this amplifier is to be inserted in the antenna lead and will improve the receiver's UHF performance by 6 to 8 db. This means that the instrument will now be capable of producing nearly error-free data at a range greater than 2 AU. Now that the package is nearly complete, the SCRA has proposed to Ames Research Center that it be flown on Pioneers C, D, and E.

Work has continued on the switching band-pass filter project. This filter uses multiple paths, each containing sampling switches and low-pass filters to obtain a band-pass characteristic. The center frequency and bandwidth are electrically tunable.

The effects of distortion on the characteristics of this filter were studied. It was found that some distortion components cancel in the output. Which components cancel depends on the number of paths in the filter. The sources of distortion in transistor amplifiers was studied and it was found that distortion was a minimum at a specific bias point. This is so because distortion due to nonlinear input impedance and nonlinear transfer characteristics tend to cancel at this bias level.

The problem of constructing a low-pass filter in an integrated circuit was considered and one solution is proposed. This solution uses the source impedance and the input capacitance of an amplifier to achieve a low-pass characteristic. The input capacitance consists of the diffusion capacitance and the miller capacitance in parallel. This capacitance can be made large by making $C_o b$ and α large and f_t small. This can be achieved by judicious choice of sheet resistivities and diffusion times. Unfortunately, this means that the low-pass filters would have to be built on a separate chip. The bandwidth of this filter is inversely proportional to I_e, thus giving a linear tuning characteristic.

The possibility of the realization of transfer function and driving point emittance function by using digital elements has been investigated. It has been theoretically worked out that any transfer function can be realized by interconnecting digital integrators and adders (digital integrators are the counter part of analog integrators and consist of two or three registers and adders). In particular, real time digital filters (the counterpart of continuous filters dealing with digital signals) can be designed in this fashion. For example, a low-pass or a band-pass filter can be constructed by using I.C. digital integrators. By using this method, filter on a chip might be accomplished.

With appropriate feedback configuration, driving point emittance functions can be proved to be realizable by using digital elements associated with analog-to-digital converters. Hopefully, inductors and capacitors can be constructed in this fashion. Many other network functions can also be implemented subject to no restrictions such as those due to the limitations of the conventional RLC elements.

The method developed should have several advantages over those existing ones. No realizability problem arises. The realization of negative elements is as easy as positive elements and no extra effort is required. The network realized can be integrated and the size of it is independent of the frequency as long as the frequency is not too high.

Work on hardware design and network function implementation is continuing. Further development and applications by the prescribed method are still under investigation.

A study of telemetry radio frequency techniques has started with the goal of improving range capability. If, for example, it were possible to detect bi-phase modulated signals in an optimum fashion without a transmitted pilot carrier, an appreciable saving in transmitter power, or extension of transmitter range, would result. Here, "optimum fashion" means the lowest possible error rate for a given transmitter power.

It turns out that this can be achieved, at least in theory, by passing the received bi-phase signal through a squarer to yield a coherent component at twice the signal carrier frequency. This new component can be tracked by a narrow phase-locked loop to yield a stable reference that can be used to demodulate the received signal.

It has been shown that this scheme will outperform any system that depends on a transmitted carrier for synchronization but how does one go about "squaring" a VHF signal? What sort of components would be best suited for the job? Some experimental work is planned that will help answer these and other questions about the practical application of the squaring-loop technique for data demodulation.

Algebraic structure theory of automata is being pursued. Two closely related problems are being worked with hopes of finding a broadly useful concept of the complexity of an automaton. Winograd [Winograd, S., On the Time Required to Perform Addition, J. Assoc. Comp. Mem., 12, 1965, 297-285] has given a lower bound for how long it takes a discrete time network to compute the binary operation for abelian groups. His result has been extended to include any group or semigroup. Thus, it can be applied to a broad class of automata in a practical sense, since it is concerned with actual realization of those automata. Winograd gives circuits which are close to optimal for abelian groups and the same has been done for some non-abelian groups. It may be possible to strengthen the above bound in some cases and to extend the class of examples.

Also under investigation are relationships between the classical flow table description of a sequential machine and the newer algebraic description. Any automaton can be viewed as a machine which does semigroup multiplication preceded by a memoryless encoder and followed by a memoryless decoder. The relationship of the properties of the maps to the properties of the flow table has not been extensively investigated. Some of the results to date concern conditions under which the maps change the machine of the semigroup to which they are attached and the relationship of the maps to the memory of the automaton.

Automata theory is potentially important in application to code generation and artificial intelligence. It is also useful as a way of viewing a communication channel which is somewhat different from conventional methods. Thus, it can be expected to yield results not obtainable in conventional theory.

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